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Triaging of respiratory protective equipment on the assumed risk of SARS-CoV-2 aerosol exposure in patient-facing healthcare workers delivering secondary care: a rapid review

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ABSTRACT

Objectives In patient-facing healthcare workers delivering secondary care, what is the evidence behind UK Government personal protective equipment (PPE) guidance on surgical masks versus respirators for SARS-CoV-2 protection?

Design Two independent reviewers performed a rapid review. Appraisal was performed using Critical Appraisal Skills Programme checklists and Grading of Recommendations, Assessment, Development and Evaluations methodology. Results were synthesised by comparison of findings and appraisals.

Data sources MEDLINE, Google Scholar, UK Government COVID-19 website and grey literature.

Eligibility criteria Studies published on any date containing primary data comparing surgical facemasks and respirators specific to SARS-CoV-2, and studies underpinning UK Government PPE guidance, were included.

Results Of 30 identified, only 3 laboratory studies of 14 different respirators and 12 surgical facemasks were found. In all three, respirators were significantly more effective than facemasks when comparing protection factors, reduction factors, filter penetrations, total inspiratory leakages at differing particle sizes, mean inspiratory flows and breathing rates. Tests included live viruses and inert particles on dummies and humans. In the six clinical studies (6502 participants) included the only statistically significant result found continuous use of respirators more effective in clinical respiratory illness compared with targeted use or surgical facemasks. There was no consistent definition of 'exposure' to determine the efficacy of respiratory protective equipment (RPE). It is difficult to define 'safe'.

Conclusions There is a paucity of evidence on the comparison of facemasks and respirators specific to SARS-CoV-2, and poor-quality evidence in other contexts. The use of surrogates results in extrapolation of non-SARS-CoV-2 specific data to guide UK Government PPE guidance. The appropriateness of this is unknown given the uncertainty over the transmission of SARS-CoV-2. This means that the evidence base for UK Government PPE guidelines is not based on SARS-CoV-2 and requires generalisation from low-quality evidence of other pathogens/particles. There is a paucity of high-quality evidence regarding the efficacy of RPE specific to SARS-CoV-2. UK Government PPE guidelines are underpinned by the assumption of droplet transmission of SARS-CoV-2. These factors suggest that the triaging of filtering face piece class 3 respirators might increase the risk of COVID-19 faced by some.

Strengths and limitations of this study

- ► The results of this study will allow for future study with a real and tangible effect towards the well-being of healthcare workers nationwide, and perhaps internationally.
- ► This article has an exceptionally broad range—from infection control, to public health, to biomechanical engineering, to industry; the hope is to increase multidisciplinary discussion.
- ► This study reviews evidence specific to a novel virus and inevitably there is a paucity of specific evidence.

INTRODUCTION

Eight hundred seven healthcare workers have died of COVID-19 worldwide as of 30 April 2020.[1] One hundred six of these tragedies have occurred in the UK.[2] On 11 April 2020, WHO COVID-19 SitRep[3] was focused solely on the need for robust reporting of SARS-CoV-2 in healthcare workers (HCWs) in order to better guide infection prevention and control measures.

To have confidence in the indications for use of respiratory protective equipment (RPE), the fluid repellent surgical mask (FRSM) and the filtering face piece class 3

(FFP3) respirator, UK HCWs must have confidence in the evidence base behind UK Government (HMG) PPE guidance (see online supplemental appendix 1 for HMG PPE guidance).[4 5]

It is widely accepted that filtering face piece respirators (that meet UK/EU standards of FFP2/3 and US standards of N95/100) (see online supplemental appendix 2 for a comparison of the various international standards of testing of respirators and surgical facemasks) are more effective in the protection of the wearer from aerosolised pathogens than FRSMs, which are not designed to protect the wearer from aerosols.[6] This is reflected in global RPE guidelines,[7–11] which demonstrate the triaging of respirators to those more likely to encounter aerosolised SARS-CoV-2, and the recommendation of FRSMs to those deemed less likely.

The need for triaging of RPE includes several considerations other than the protective ability of these respirators. These include the shortage of global stock and supply,[7–11] the need to ensure that low-income to middle-income countries are also able to access RPE,[12] and the relative risk of SARS-CoV-2 exposure by the current understanding of the transmission of virus.

The latter consideration causes concern. HMG PPE guidance[4] on the indications for use of FFP3 respirator relies on two assumptions. First, that its list of aerosol generating procedures (AGPs)[5] and high-risk areas are exhaustive. Second, that the droplet theory of SARS-CoV-2 transmission[13 14] is correct. If either of these two postulates are incorrect and the role of aerosolisation transmission in SARS-CoV-2 is greater than currently thought, the current triaging system of respirators may result in HMG PPE guidance indicating a less effective form of RPE in a higher-than-expected risk setting.

This rapid review aims to determine the evidence base to the protective ability of respirators versus FRSMs to aerosolised SARS-CoV-2.

METHODS

This is a rapid systematic review of heterogenous studies with no summary estimate due to vastly different study protocols.

Review question

Following the widely used PICO structure,[15] the research question was framed as:

> In patient-facing healthcare workers delivering secondary care, what is the evidence behind UK Government PPE Guidance on surgical masks versus respirators for SARS-CoV-2 protection?

Full PICO strategy and search strands are available in online supplemental appendix 3.

Preliminary search for similar reviews

Two similar systematic reviews were found.[16 17] The focus of the UK-based review by Greenhalgh *et al*[16] was on the efficacy of FRSMs and respirators in primary care; while in 2016, Smith *et al*[17] did not focus on SARS-CoV-2 prevention, rather respiratory disease in general in Canada. These reviews employed a similar methodology but varied in their population[16] and their outcomes.[17] Greenhalgh *et al* found no difference between FRSMs and FFP3 respirators in primary care. Smith *et al* found insufficient data to draw conclusions of the protective ability of N95 respirators compared with FRSMs.

Search strategy

Following keywords were searched: 'respirator', 'surgical mask', 'mask', 'FFP', 'FFP3', 'PPE', 'personal protective equipment' AND 'viral', 'infection', 'respiratory', 'covid', 'COVID-19', 'coronavirus', 'SARS-CoV-2'.

Full PICO strategy and search strands are available in online supplemental appendix 3.

Authors PR and JS conducted the database search and eligibility check independently.

Databases searched

1. PubMed/MEDLINE.
2. Google Scholar.
3. Grey literature search—by searching for references behind the RPE guidelines of the UK, the USA and EU/EEA(bodies outside of the UK were searched since it was felt that these populations have similar demographics and pandemic response measures).
4. Snowball search—by reviewing the references of included and excluded articles, and the references of these references, for eligibility and appraisal.

Eligibility criteria

Table 1 shows the eligibility criteria for search results.

Critical appraisal

The authors independently used the relevant Critical Appraisal Skills Programme (CASP) checklists.[18] All studies were included for qualitative analysis since it is noted that during a time of global crisis, the need for rapid evidence based on a novel virus may reduce the viability of gold-standard randomised controlled trials and shorten timelines for follow-up. The need to appraise studies thoroughly for 'bad science' is vital during such a time, and therefore comments arising from critical appraisal of all articles included are attached to their results to allow for informed decision making.

Consensus meeting

Disagreement resulted in full-text review for eligibility and, if accepted, individual appraisals conducted independently. A third author was tasked to review for eligibility had there been any further disagreements on full-text review.

Quality assurance

The Grading of Recommendations, Assessment, Development and Evaluations (GRADE) tool was used to systematically and reproducibly assess the quality of the

Table 1 Eligibility criteria for articles discovered through database searching

Inclusion criteria	Exclusion criteria
Title screen: one of the key terms above	Non-English language studies due to language abilities of authors and rapid timelines
Abstract screen: could not rule out respirator versus FRSM comparison in full text	Irrelevant titles
Full text: any comparison between FRSM and respirator	Search results not specific to FRSMs, FFP respirators or SARS-CoV-2
Any study design containing primary data	Journals not accessible online
Published on any date	
Preprints/Unpublished articles found online	
Any studies cited on UK Government COVID-19 PPE advice website	

FFP, filtering face piece; FRSM, fluid repellent surgical mask; PPE, personal protective equipment.

included studies. Authors PR and JS undertook quality assessment with GRADE independently. On completion, the authors allocated the mean of their independent individual GRADE subscores to each study.

Data management

Figure 1 shows a Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram[19] displaying

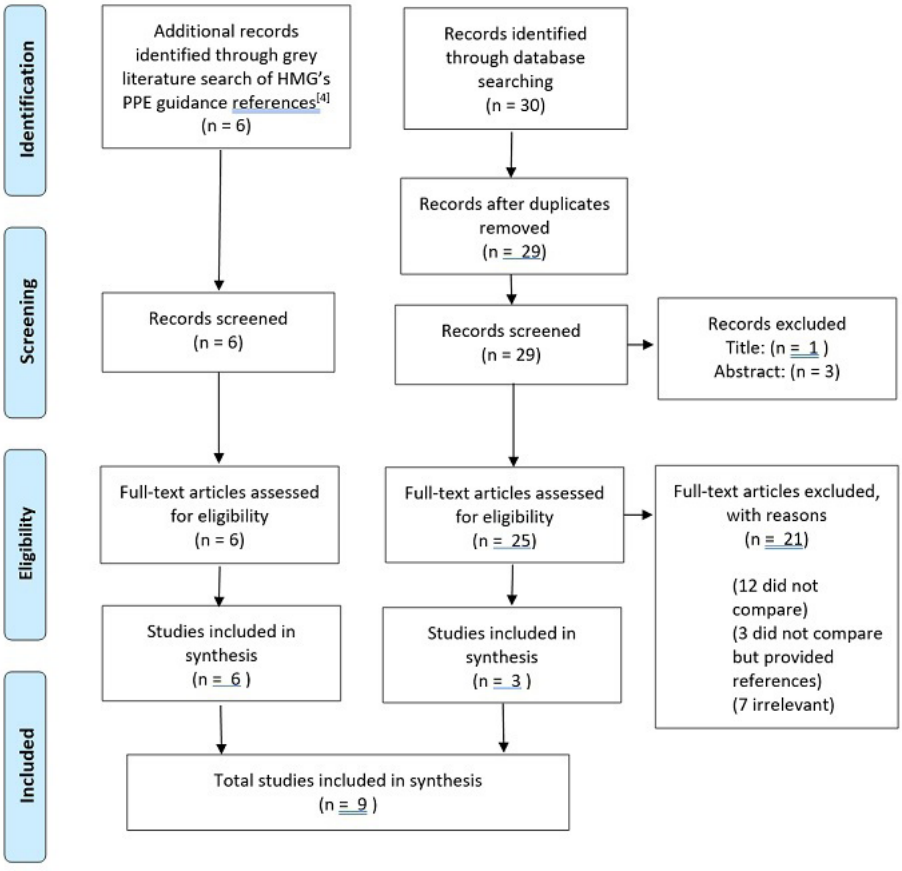

Figure 1 Data management of screened articles through a Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.[19] Thirty results were returned to our SARS-CoV-2-specific search strand. Four articles did not meet our criteria for full-text screening. Three articles were included for review. In 12 of the full-text screens, there was no comparison between respiratory protective equipment (RPE), 7 were irrelevant and 3 did not compare RPE but provided references for screening references of references. Six articles were identified through grey literature search of UK Government (HMG) personal protective equipment (PPE) guidance website. Since this was a key subject of review, all articles referenced by HMG were included.

data management of search results.

Data extraction

Data from the nine included articles were extracted independently onto independent electronic spreadsheets.

Databases were re-searched in the timeframe 11–30 April 2020 to identify new literature. An additional similar systematic review was discovered.[20] This did not contain primary data so was not included, however is discussed as a similar study. During the peer-review process of this manuscript, another similar review[21] was published, the results of which are discussed in this review.

Result synthesis

Due to the heterogeneity of study designs and the parameters of results, data extracted from accepted articles were compared directly.

For laboratory studies, these data included study design, research question, masks/respirators tests, testing particle/pathogen, findings and appraisal comments.

For clinical studies, these data included setting, participants, interventions, outcomes and limitations raised in appraisal.

Patient and public involvement

This study did not include patient or public involvement due to the rapid nature of the review.

RESULTS

Review of laboratory studies comparing respirators with FRSMs

Three key laboratory studies were identified that met the inclusion criteria. All studies used a methodology that evaluated the effectiveness of masks by measuring the concentration of particles (either NaCl aerosol or live Influenza) between the mask/wearer and externally, hence determining a property known as protection factor (PF) (PF is a ratio of the test particle/pathogen per unit volume on the outside of the test mask/respirator compared with that on the inside, over a standardised time frame with standardised temperature, humidity and windspeed).[21]

Lee *et al* compared the PF of FRSMs with FFP2 and FFP3 respirators in filtering NaCl aerosol when donned on human subjects.[22] It was found that respirators offered an average PF of 24.5 vs 1.7 for FRSMs. Despite this relative improvement, in several cases the measured PFs for the masks did not meet the standards they were approved to. Overall, the PF afforded by the mask was affected by the quality of fit test. A key limitation of the study was that NaCl surrogate particles used had a wide range of particle sizes, and therefore the ability of the masks to filter in the specific particle size range of those in the size range of respiratory viruses (including SARS-CoV-2) was not measured.

In order to more accurately reproduce the particle size of viral and bacterial aerosols, the Health and Safety Laboratory used live influenza and NaCl aerosol with controlled particle size.[6] The study reported a similar PF to Lee *et al*[22] of 2 for FRSMs, and a similar increase in effectiveness for respirators (17 times increase). Live, infectious particles were detected behind all FRSMs after testing. This indicates that the influenza sized particles could either penetrate or circumnavigate the mask and remain infectious to the user. However, a key limitation of this study was that the same effect was not reported for respirators due to testing issues—preventing comparison between the two types of mask.

He *et al*[23] identified that the PF difference between FRSMs and respirators also varies according to breathing rate, or mean inspiratory flow (MIF). At the lowest MIF, FRSMs were 108 times more effective, while just 13.4 at the highest MIF. Akin to the methodology by Lee *et al*,[22] NaCl aerosol was used as a substitute for virus. During the study, the same respirator was used up to 20 times. Respirators are known to clog with increased use.[22] As this effect was not quantified or otherwise accounted for, its effects on overall filter performance cannot be assessed.

Review of clinical trials comparing respirator with FRSMs

Six clinical studies were identified that met the inclusion criteria. The number of subjects varied between 41 and 2862. In contrast to laboratory studies, where PF was used as a metric of effectiveness, the identified clinical studies used symptomatic viral infection of HCWs in healthcare environments as a measure of mask effectiveness.

Radonovich *et al*[24] and Loeb *et al*[25] both found no significant differences in infection rates between HCWs wearing N95 (FFP2 equivalent) respirators and FRSMs. Both studies used self-reported data to track respiratory symptoms. If detected, the HCW would provide a laboratory sample to confirm a positive case of influenza. During both studies, the use of infection control and PPE use in the respective institutions was observed and evaluated. A limitation of the study by Radonovich *et al*[24] was that only symptomatic participants were PCR-tested. Therefore, asymptomatic but infected individuals were not included. Additionally, the results were not stratified for influenza vaccination. A limitation of the study by Loeb *et al*[25] was that data on other infection control measures (hand hygiene, or use of gloves and gowns) were not collected, nor whether participants had received influenza vaccination.

In contrast, MacIntyre *et al* reported a statistically significant reduction in self-reported respiratory symptoms between groups of HCWs employing either targeted FRSM or N95 use (11.8% vs 17%).[26] Further reduction in infection rate was measured if a respirator was worn continuously and not just during AGPs. However, when symptomatic cases were laboratory tested, no significant differences in confirmed cases between the two groups were found. A later study from the same group[27] did find a reduction of laboratory confirmed cases in N95 vs FRSM, but no difference between those who wore FRSMs

and those who did not wear masks. A limitation of this study was that only symptomatic participants were tested.

Ng *et al* retrospectively assessed the symptoms of 41 HCWs (divided into FRSM and respirator cohorts) after exposure to a single patient with SARS-CoV-2, lab testing all workers every 1–5 days.[28] During the study timeframe, 85% of workers were exposed to an AGP from the patient. During the study, none of the HCWs tested positive for the virus, and therefore no difference between the mask wearing groups was detected. Loeb *et al* conducted a retrospective study based on interviews with HCWs exposed to SARS with a similar sized cohort.[29] In contrast to the study by Ng *et al*,[28] this study showed an almost 80% reduction in risk of infection for nurses who consistently wore masks (either FRSM or N95). On comparison of use of N95 respirators wih FRSMs, the relative SARS risk associated with the N95 mask was half that for the surgical mask. However, due to the small sample size, the result was not statistically significant. A limitation of this study was its small sample size (n=43) likely underpowering its results. The retrospective methodology used self-reported retrospective data, and is therefore subject to recall bias.

There were common methodological issues to all of the clinical studies that may affect the reported results. First, no study accurately accounts for vaccination history—either a percentage of the cohort are assumed to be vaccinated, or simply omitted as a limitation. Second, the activities of each HCW outside of the working environment (eg, unprotected interaction with other individuals at risk of infection) were not tracked or considered.

A summary of the results of this review is mentioned in table 2. Table 3 tabulates the GRADE quality assessment conducted on included studies in this review. More details of each of the evaluated studies can be found in online supplemental appendix 4.

DISCUSSION

Statement of principal findings

All three laboratory studies suggest respirators are significantly more effective than facemasks in PFs. However, an important limitation is the need for generalisation from the laboratory setting to the clinical setting. It was difficult to compare clinical studies as different methodologies and parameters were used to define the protective ability of each form of RPE. Studies were often underpowered and might suffer from confounding variables.

Both the quality and quantity of evidence regarding the use of RPE against SARS-CoV-2 is low. This is understandable given the novel nature of the COVID-19 pandemic. It was found that there is a paucity of evidence specific to SARS-CoV-2, with the current evidence being very low quality. On review of the references within HMG PPE guidance,[4] indirectness and imprecision were detected in included studies. Indirectness was due to the need to use low-quality evidence from other pathogens as a surrogate due to the paucity of SARS-CoV-2-specific evidence. Imprecision was usually due to either small population sizes or the inability to stratify for confounders.

Strengths and weaknesses of the study

The CASP checklist for the appropriate study designs was used to critically appraise studies while GRADE methodology was used to assess the quality of evidence in included studies. It was noted that there is a paucity of evidence regarding RPE specific to SARS-CoV-2. HMG's PPE guidance[4] was found to reference non-SARS-CoV-2 and non-FFP3-specific studies, therefore these were included for review. Any study design containing primary data was included. Non-English language studies were not included, although translated studies were screened. Other databases such as the Cochrane Library, could have been searched, although unpublished literature and public health reports were discovered through snowball searching. Due to the heterogeneity of study designs, and statistically insignificant results, it was not possible to perform a quantitative analysis. The potential harm of RPE use, such as pressure sores and stress, is poorly documented and requires further study for mitigation and improvement.

This review aimed to ascertain and evaluate the evidence base behind RPE policy specific to SARS-CoV-2 in order to most effectively protect HCWs from SARS-CoV-2 infection. While the subject is novel, this review adds to the rapidly expanding discussion on the use of RPE in the inpatient setting.

Strengths and weaknesses in relation to other studies, discussing important differences in results

This review found just one study that directly compares FRSMs and respirators. Ng *et al*[28] conclude that FRSMs and N95s are equally effective. Limitations of this study include retrospective design, small sample size and a wide range of scenarios defined as 'exposure'. There is no stratification of confounding variables such as age, sex, health, community exposure to SARS-CoV-2, or exposure to other patients with COVID-19. In the participants tested, none tested positive for SARS-CoV-2 in either intervention. It is unclear how quantitative analysis was performed. No retrospective significant difference was found in SARS-CoV-2 test results of these HCWs. While this does not prove either more effective, it also does not support the study conclusion that FRSMs and N95s are equally effective.

On re-searching of the literature, two similar systematic reviews[20 21] were published during the study period of this review. One, by Bartoszko *et al*[20] was a systematic review and meta-analysis of four clinical randomised controlled trials (RCTs) comparing FRSM and N95 use. Three[24 25 27] of the four studies included in the review by Bartoszko *et al*.[20] were included in our review. Bartoszko *et al*[20] used search terms specific to RCTs, not specific to SARS-CoV-2/COVID-19, and excluded laboratory studies or tests on manikins. These authors also highlight the paucity and low quality of evidence comparing FRSMs

Table 2 The country, subjects, test/population size, key variable, key comparator and key outcome of included studies

Author	Subject	N (tests)	Key dependent variable	Key test group	Key outcome
Laboratory studies					
Lee *et al*[22] Taiwan	Human	30	PF to NaCl	FRSMs vs FFP2/FFP3	Respirators provide up to 16× higher PF in measured conditions
Gawn *et al*[6] UK	Dummy+human	19	PF to NaCl and to live *influenza* virus	FRSMs vs FFP1/FFP2/FFP3	Respirators provide up to 17× higher PF in measured conditions. Live influenza virus penetrates/circumnavigates FRSMs
He *et al*[23] USA	Dummy	20	PF to NaCl	FRSMs vs N95	Respirators provide up to 108× higher PF in measured conditions, but is reduced to 13.4× at high MIF
Clinical studies					
Radonovich *et al*[24] USA	7 US hospitals	2862	Laboratory-confirmed *influenza*	FRSM vs N95	No significant difference in infection rates between the two groups
Loeb *et al*[25] Canada	8 Canadian hospitals	446	Respiratory symptoms Laboratory-confirmed *influenza*	FRSM vs N95	No significant difference in infection rates between the two groups
MacIntyre *et al*[26] China	19 Chinese hospitals	1669	Respiratory symptoms Laboratory-confirmed *influenza*	FRSM vs N95 Targeted vs continuous use	Symptom rates were highest in FRSMs (17%), followed by respirators (targeted, 11.8%), followed by respirators (continuous, 7.2%)
MacIntyre *et al*[27] China	15 Beijing hospitals	1441	Respiratory symptoms Laboratory-confirmed *influenza*	FRSM vs N95 vs no mask	Respirators were statistically more protective than control group
Ng *et al*[28] Singapore	1 Singaporean hospital	41	Laboratory-confirmed SARS-CoV-2	FRSM vs N95	No confirmed SARS-CoV-2 cases—efficacy difference between two groups not confirmed
Loeb *et al*[29] Canada	2 Canadian hospitals	43	Retrospective recall of SARS symptoms	FRSM vs N95 vs no mask	80% reduction in risk of infections using mask vs no mask, but no difference between mask types

FFP, filtering face piece; FRSM, fluid repellent surgical mask; MIF, mean inspiratory flow; PF, protection factor.

Table 3 The quality of evidence per GRADE methodology and is to be used in conjunction with table 2

Study	Outcome	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Quality
Lee *et al* [22] Lab	PF vs NaCl particles of varying sizes	Not serious	Not serious	Serious	Not serious	Undetected	⊕ VERY LOW
	Relationship between fit factor and PF	Not serious	Not serious	Serious	Not serious	Undetected	⊕ VERY LOW
Gawn *et al* [6] Lab	PF	Not serious	Not serious	Serious	Not serious	Undetected	⊕⊕ LOW
	Fit factor	Not serious	Not serious	Not serious	Not serious	Undetected	⊕⊕ LOW
He *et al* [23] Lab	Total inward leakage	Not serious	Not serious	Serious	Not serious	Undetected	⊕⊕ LOW
Radonovich *et al* [24] RCT	Incidence of laboratory-confirmed *influenza*	Not serious	Not serious	Not serious	Serious	Undetected	⊕⊕ LOW
	Incidence of viral respiratory illness	Not serious	Not serious	Not serious	Serious	Undetected	⊕⊕ LOW
Loeb *et al* [25] Cohort	Incidence of laboratory-confirmed *influenza*	Serious	Not serious	Serious	Not serious	Undetected	⊕⊕ LOW
	Incidence of non-*influenza* viruses	Serious	Not serious	Serious	Not serious	Undetected	⊕⊕ LOW
MacIntyre *et al* [26] RCT	Clinical respiratory illness	Not serious	Not serious	Not serious	Not serious	Undetected	⊕⊕⊕ MODERATE
	Incidence of laboratory-confirmed pathogens	Not serious	Not serious	Not serious	Serious	Undetected	⊕⊕ LOW
MacIntyre *et al* [27] RCT	Incidence of symptomatic laboratory-confirmed bacterial respiratory tract infections	Not serious	Not serious	Not serious	Serious	Undetected	⊕⊕⊕ MODERATE
	Co-colonisation with bacterial/viral infection	Not serious	Not serious	Not serious	Serious	Undetected	⊕⊕⊕ MODERATE
Ng *et al* [28] Case report	Laboratory-confirmed SARS-CoV-2	Serious	Not serious	Very serious	Serious	Undetected	⊕ VERY LOW
Loeb *et al* [29] Retrospective	Confirmed SARS infection	Serious	Not serious	Serious	Serious	Undetected	⊕ VERY LOW

PF, protection factor; RCT, randomised controlled trial.

and respirators. Their review adjusted for the collation of results from cluster RCTs with individual RCTs. However, the review was not specific to SARS-CoV-2, nor was the meta-analysis of aggregate data specific to any coronavirus. Similar to our review, that team[20] draws outcomes from laboratory-confirmed illnesses of other viruses to postulate conclusions. The review by Bartoszko *et al*[20] might be limited by the exclusion of other study designs. It is unclear why three studies were included for analysis externally to their search strategy at a late stage, nor why an RCT[27] included in our review, providing statistically significant findings, was excluded by that team.

The second, a rapid review of facemasks and respirators by MacIntyre *et al*,[21] was similar to the review by Bartoszko *et al*[20] in that it included only RCTs. Similar to this review, MacIntyre *et al*[21] focused on SARS-CoV-2 and included data on other respiratory transmissible viruses and studies from community, healthcare and source control settings. MacIntyre *et al*[21] also find that comparison between different RCTs is difficult due to the varying parameters used to define 'safe'. Akin to our review, MacIntyre *et al*[21] also find that continuous respirator use is effective in the protection of HCWs when compared with intermittent use. They also comment on the lack of current understanding of the degree of aerosolisation of SARS-CoV-2 outside recognised AGPs, and the role this plays in transmission.

Meaning of the study: possible explanations and implications for clinicians and policymakers

There is no high-quality evidence regarding the efficacy of RPE in protecting HCWs against SARS-CoV-2 transmission. The evidence base suggests FFP3s may be a more effective form of RPE than FRSMs. There is uncertainty on the transmission mechanism of SARS-CoV-2.[30] If SARS-CoV-2 aerosolisation is more common than thought, FFP3 respirators would be indicated in a greater variety of settings as first line. There are challenges to the droplet model of respiratory illness transmission.[31] Procedures classified as AGPs vary in international guidance.[7–11] If the droplet model is inaccurate, aerosolisation might occur to a greater degree than currently thought, portending increased use of FFP3 respirators. Given this uncertainty, HMG PPE guidance[4] should take a cautious approach rather than risk underprotecting staff. RPE guidance is increasingly stock driven.[8–11] If RPE must be triaged due to unavailability of stock, FRSM wearing HCWs may be exposed to aerosolised SARS-CoV-2.

Unanswered questions and future research

Further rigorous study is required into the transmission of SARS-CoV-2, as recent studies liken it more to SARS-CoV-1 than to influenza.[30] HMG PPE guidance[4] is based on preparedness for an *influenza* pandemic.

The validity of the droplet versus aerosol dichotomy of respiratory illness transmission is uncertain.[31] It must be substantiated since it underpins HMG PPE guidance on RPE. This may have wider implications as nations consider guidance on large-scale mask-wearing interventions as a public health measure.

Expedited research is required to further understand aerosol-generating procedures, including an effort to standardise the classification of AGPs by different organisations as AGPs are the key indication for RPE triaging in HMG PPE guidance.[4] This is even more pertinent if COVID-19 becomes an established disease.

HMG PPE guidance on the indications for use of FFP3 and FRSM is underpinned by the droplet theory of transmission of SARS-CoV-2, based on the flow chart suggested by Coia *et al*[32] as shown in figure 2.

Hence, an immediate consideration for the choice of RPE in patient-facing HCW is that an FRSM may not be 'safe', as it is difficult to define 'safe'. Due to lack of stock and supply, FFP3 respirators may have to be prioritised for those exposed to areas of greatest aerosolisation of SARS-CoV-2. This is further compounded by our lack of understanding of the aerosolisation of SARS-CoV-2. An FFP3 respirator may provide greater protection than an FRSM given the uncertainty on the aerosolisation of SARS-CoV-2. It is suggested that if there were an unlimited stock of FFP3 respirators, the guidance would be that all inpatient facing HCWs would wear them continuously.

CONCLUSION

HCWs away from work, self-isolating or on sick leave due to COVID-19 reduce the health system's capacity to deal with the ongoing pandemic.[3] In order to reduce sickness burden on health systems, local policy makers must be able to make informed, evidence-based decisions on their choice of RPE.

This review concludes that the evidence base for HMG's PPE guidelines[4] is not based on SARS-CoV-2 and requires generalisation from low-quality evidence in which other pathogens/particles were tested. There is a paucity of high-quality evidence regarding the efficacy of RPE specific to SARS-CoV-2. HMG's PPE guidelines are underpinned by the assumption of droplet transmission of SARS-CoV-2.

It is evident from the WHO,[33] the European Centre for Disease Prevention and Control[9–11] and the Centers for Disease Control and Prevention[8] guidance that the indications for the use of RPE are not based solely on the protective abilities of respirators and FRSMs. Instead, a triaging system based on an expected shortage of global stock and supply, combined with current understanding of likelihood of exposure to aerosolised SARS-CoV-2 is used.

There is active discussion regarding the droplet transmission of SARS-CoV-2 with an accepted uncertainty in understanding.[30 31] Given this uncertainty, a cautious approach should be taken in the protection of HCWs. This review found that in all laboratory studies respirators were more protective to the wearer than FRSMs in all parameters tested. In the clinical studies reviewed, the only statistically significant finding was that respirators

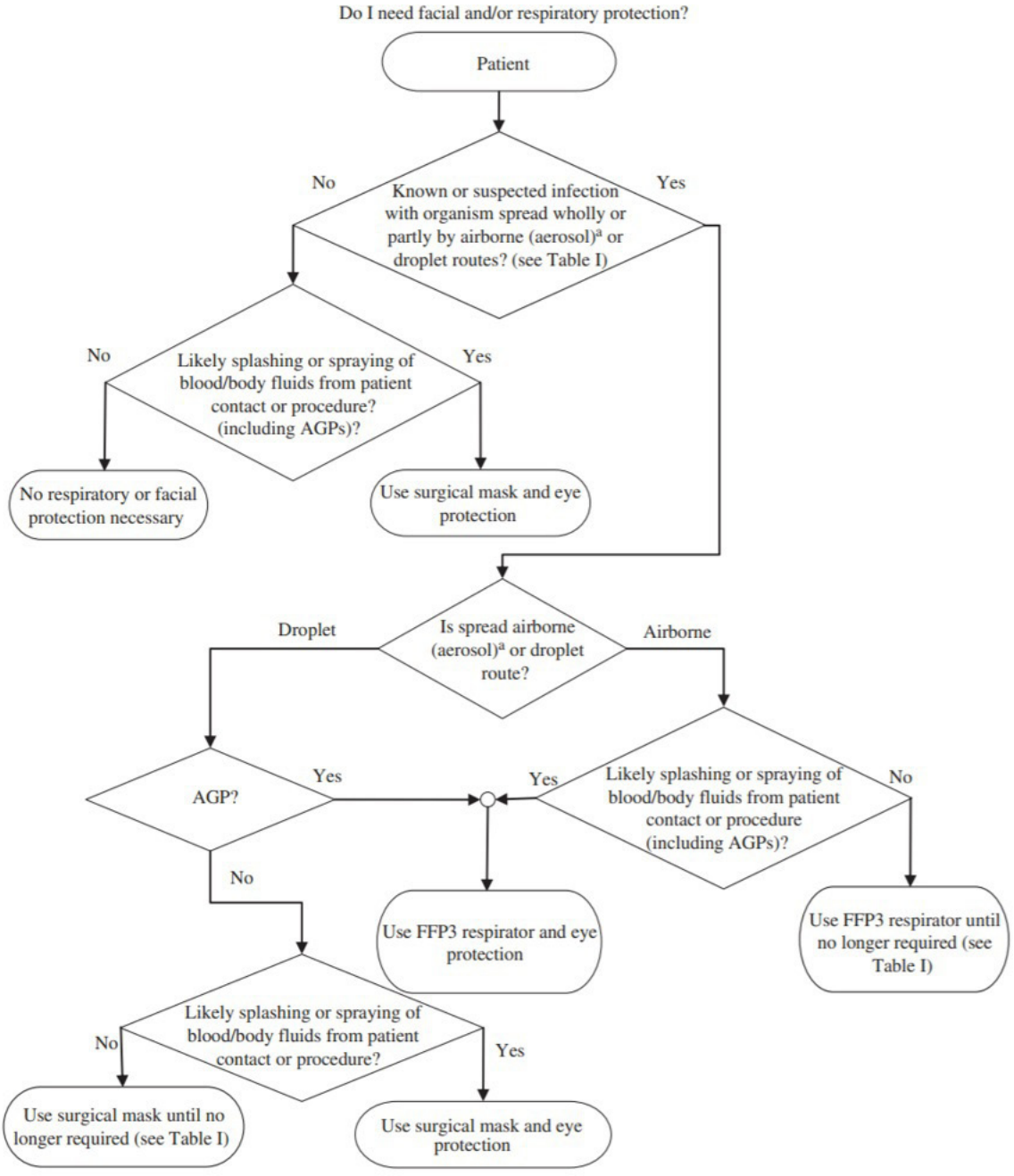

Figure 2 The basis for triaging of respiratory protective equipment (RPE) by Coia *et al*.[32] Indications for filtering face piece class 3 (FFP3) respirator versus fluid repellent surgical mask (FRSM) is underpinned by the droplet transmission of the virus in question.

provided significant protection against bacterial-viral coinfection compared with FRSMs. No statistically significant evidence was found to support the conjecture that an FRSM might provide the same level of protection as a respirator against SARS-CoV-2, or indeed any tested live virus or inert submicron particle. Therefore, use of a respirator would be the more cautious option.

While the triaging of RPE due to a lack of global stock is understandable and appropriate during the strains of a pandemic, it must be noted that by increasing the protection of some through the provision of respirators, HMG PPE guidance might be increasing the risk of COVID-19 faced by others.

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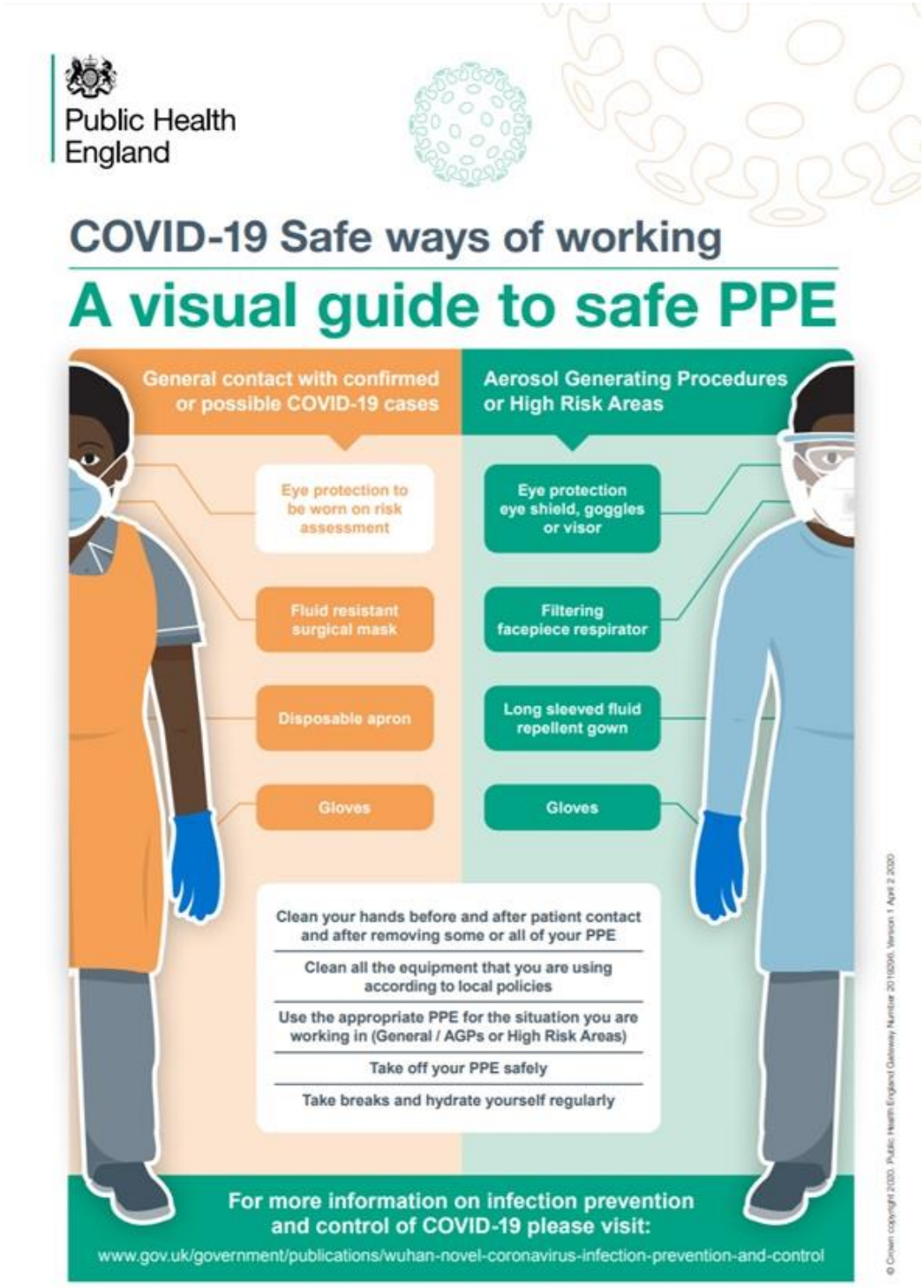
Triaging of Respiratory Protective Equipment on the assumed risk of SARS-CoV-2 aerosol exposure in patient-facing healthcare workers delivering secondary care: a rapid review

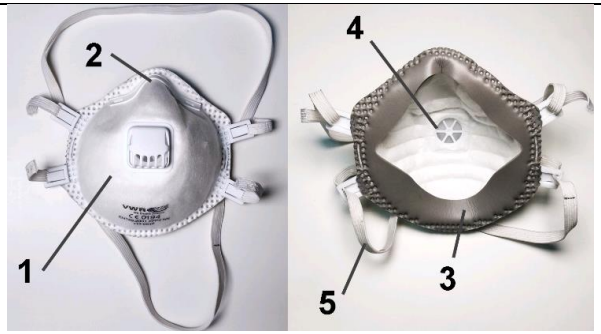
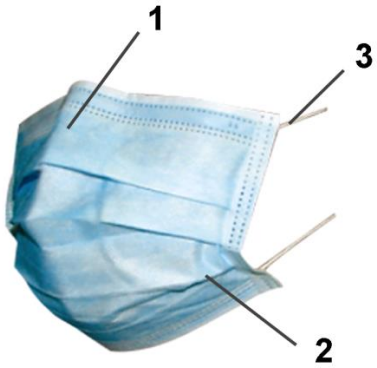
P Ramaraj, JT Super, R Doyle, C Aylwin, S Hettiaratchy. 2020.

Appendices

Appendix 1 – HMG's PPE Guidance as at 17th April 2020



Appendix 2 – An explanation of international nomenclature and testing standards surrounding respirators and surgical facemasks

<table>
<tr><td rowspan="2">Key Features</td><td colspan="4"> 
</td><td colspan="3"> 
</td></tr>
<tr><td colspan="4">(1) Dense polymer material (usually melt blown polypropylene) with sub-micron pores
(2) Moulded, countered shaping or metal nose clip for close fit with face
(3) Polymer lip creating airtight seal with skin
(4) Exhaust valve (optional) to reduce exhalation pressure
(5) Adjustable straps for close face fit</td><td colspan="3">(1) Dense polymer material (usually melt blown polypropylene) with micron sized pores
(2) Pleated, expandable form for loose coverage of all face shapes
(3) Non-adjustable elastic straps/ fabric straps for user to tie to desired length</td></tr>
<tr><td colspan="2">Relevant European standards</td><td colspan="4">EN 149:2001</td><td colspan="3">EN 14683:2019, ISO 22609:2004, ISO 10993</td></tr>
<tr><td rowspan="2">Specific models [+]</td><td>European</td><td>FFP1,</td><td>FFP2</td><td>FFP3</td><td>Type I</td><td>Type II</td><td>Type IIR</td></tr>
<tr><td>USA</td><td>N95</td><td>N99</td><td>N100</td><td>Level 1</td><td>Level 2</td><td>Level 3</td></tr>
<tr><td colspan="2">Aerosol leakage</td><td colspan="4">Requires seal with skin and a total inward leakage of air of <5%</td><td colspan="3">No seal with skin and protection against leakage</td></tr>
<tr><td colspan="2">Particle filter efficiency*</td><td colspan="4">99% of 0.6 um mean diameter particles to wearer</td><td colspan="3">98% of 3 um mean diameter particles through filter material.
No testing for wearer exposure.</td></tr>
</table>

[+]Highlighted are most relevant for this review as the models supplied by the NHS for HCW protection

*Efforts have been made to harmonize difference test methods to compare filter efficiency

Appendix 3 – PICO Strategy and PubMed/MEDLINE Search Strand

Population: patient-facing healthcare workers in secondary inpatient care.

Intervention: surgical masks (including international nomenclature: medical mask, fluid-repellent surgical mask).

Comparison: respirators (defined as FFP3, FFP2, FFP1, N95, N99 or N100 to include international nomenclature during a global crisis and variation of legal testing standards internationally).

Outcomes: SARS-CoV-2 protection (this ensured a broad outcome in terms of parameters used to define "protection" but maintained a SARS-CoV-2 specific search).

PubMed search strand:

("respirator" AND/OR "surgical mask" AND/OR mask AND/OR FFP AND/OR "FFP3" AND/OR PPE AND/OR "personal protective equipment") AND ("viral" AND/OR "infection" AND/OR "respiratory" AND/OR "COVID" AND/OR "COVID-19" AND/OR "coronavirus" AND/OR "SARS-CoV-2")*

Appendix 4 – Full appraisal of all included studies using the appropriate CASP checklist

Laboratory studies

Author	Study Design	Question	Mask/Respirator	Pathogen/Particle	Findings	Appraisal
Lee SA., et al. 2016.[21]	Human (N = 30)	Do respirators with higher filtration efficiencies provide greater protection when human subjects don the respirators?	1x FFP2, 1x FFP3 with 3x FRSM	NaCl	1. The respirators provided between 11.5 to 15.9 times the protection of the FRSMs, suggesting that FRSMs are not a good substitute for respirators when concerns exist about airborne transmission of bacterial and viral pathogens. 2. 18.3% of the tested FFP2 respirators had PFs <10, and 41.7% of the tested FFP3 respirators had PFs[1] <20, indicating that the European standard for APF of 10 for FFP2 respirators and 20 for FFP3 respirators may overestimate the actual protection offered by these respirators against particles in the size range of 0.093–1.61 µm.	+ Standardised and peer reviewed method of testing. + Controlled for age, sex, facial anatomy and hair, fit testing, smoking, previous respiratory use, allergies, cardiovascular/respiratory illness, and drinking within 30 mins of testing. + Standardised for loss of particles into the sampling devices' lines prior to detection. - No mention of randomisation or blinding. - Small study population (N = 30), narrow age range (18 – 24 year olds), all of Taiwanese origin, respirators from only two companies. Difficult to generalise to wider global population and respirators produced by other companies.

[1] Protection Factor: a ratio of the test particle/pathogen per unit volume on the outside of the test mask/respirator compared to that on the inside, over a standardised time frame with standardised temperature, humidity, and windspeed.[21]

					3. The protection factors of respirators against particles in the size range of 0.093–1.61 µm were not size dependent. The size ranges of viral and bacterial particles fall into this size range, and they are expected to have similar PFs. 4. Correct fit is an important consideration.	
Health Safety Laboratory. 2008.[6]	Dummy & Human	What is the contribution of surgical masks in the protection against any residual aerosol risk of airborne particles generated from a simulated sneeze (including those that contain live, infectious influenza virus)?	11x FFP (2x FFP1) (4x FFP2) (5x FFP3) 8x FRSM (5x Tie) (3x Strap)	NaCl & Live *Influenza A*	1. There is a lack of scientific evidence regarding the protective effect of surgical masks against infectious aerosols (with reference to worker safety) to support HSE's pandemic planning activities. 2. Surgical masks will achieve a mean reduction factor[2] of 2 against a	+ Controlled for *Influenza A* in bioaerosol challenge by calculating reduction factor. + Standardisation of inert aerosol generation with particle size of human cough. + Standardisation of fit factors for FFP respirators - No mention of blinding. - Unable to fit FFP respirators to the Sheffield dummy, therefore FFP respirators not tested with live viable *Influenza A*. - Inert testing on one human does not control for different face anatomy

[2] $Reduction\ Factor = \frac{Particle\ concentration\ outside\ the\ facepiece}{Particle\ concentration\ inside\ the\ facepiece}$

					simulated sneeze of inert airborne particles. 3. The efficiency of FRSMs against inert airborne particles is greatly reduced compared to respirators. 4. Live, infectious virus was extracted in enumerable quantities from the air from behind all the surgical masks tested. This suggests that influenza virus can survive in aerosol particles and bypass/penetrate a surgical mask and that a residual infectious aerosol hazard may exist. 5. Surgical masks provide a 6-fold reduction in exposure to live, infectious *Influenza A* virus. By contrast, properly fitted respirators provide at least a 100-fold reduction.	- Bioaerosol challenge from only one distance (70cm). - Does not account for environmental factors on *Influenza A* transmission such as humidity, temperature, ventilation.

He X., et al. 2014.[22]	Dummy	How does breathing frequency affect N95 and FRSM performance against viral and other submicron particles?	1x N95, 1x FRSM	NaCl	1. The N95 filtered 13.4 times more particles than the FRSM at the highest Mean Inspiratory Flow (MIF) and 108.2 times more particles at the lowest MIF. (N95 P_{filter} = 0.72% at 85 L/min (MIF); 0.05% at 15 L/min ($p < 0.0001$). FRSM: P_{filter} = 9.65%; MIF = 85 L/min; P_{filter} = 5.41%, MIF = 15 L/min, ($p < 0.0001$)). 2. The FRSM allowed the Total Inspiratory Leakage (TIL) of 18.9 times more particles at 10 breaths/minute and 14.9 times more at 30 breaths/min than the N95. N95: (10 breaths/min, mean TIL = 1.22%; 30 breaths/min, mean TIL = 1.73% ($p > 0.0025$). FRSM: (10 breaths/min, mean TIL = 23.1%; 30 breaths/min, mean TIL = 25.7%) ($p < 0.0025$)).	+ measurements controlled for NaCl concentrations higher than environmental concentrations of virus. + utilised reliable and reproducible parameters. + controlled for temperature and humidity. + randomised independent variables to reduce risk of bias. - Only one model of respirator and one mask. - RPE removed after 20 tests, so later tests will be impacted by NaCl loading/"clogging". - RPE taped to mannequin for P_{filter} testing. - Unclear exactly how many tests were performed.

Clinical trials

Author	Setting	Participants	Interventions	Findings	Appraisal
Radonovich, et al. 2019.[23]	7 US medical centres; outpatient setting	2862 randomized participants	N95 vs FRSM	1. N95 respirators vs FRSM as worn by participants in this trial resulted in no significant difference in the incidence of laboratory-confirmed influenza	Randomised Control Trial. 1. Adherence to infection control was evaluated throughout the study. 2. Exposure to patients, co-workers and others with respiratory illness was self-reported in a diary. 3. Participants were recruited from the outpatient setting 4. Testing methodology - only tested using RT-PCR when symptomatic thus may have missed asymptomatic individuals, as well as 2 random swabs during the study. 5. Only assumed that 65% participants were vaccinated against the influenza virus (they did not collect this data) yet they were measuring infection by influenza. 6. No protective equipment was worn outside the workplace. 7. Only N95 and FRSM masks were tested so authors warn against making generalisations about effectiveness.

Loeb, et al. 2009.[24]	8 hospitals in Ontario, Canada: EDs, AMUs and Paediatric units	446 nurses	N95 vs FRSM	There were no significant differences between the FRSM and N95 respirator groups in respiratory syncytial virus type B, metapneumovirus, parainfluenza 3, rhinovirus-enterovirus, or coronaviruses. Only 12% of lab confirmed viral infections had fever. No difference between FRSM and targeted N95 use.	1. The study was abandoned at the start of the 2009 influenza pandemic when all nurses were advised to wear N95. 2. Self-reporting of data during 2x weekly questionnaires. 3. Only tested if self-reported as symptomatic and sent a test to perform themselves. 4. No mention of vaccination history. 5. Audits conducted were done via telephone to assess whether patients were admitted to the wards with febrile respiratory illness/influenza. If so, an auditor went into the hospital to observe the use of the protective equipment. 6. Only one room entry was recorded per observation. 7. Emergency departments were not audited. 8. Co-workers and families were not surveyed as a source of infection. 9. Hand hygiene, use of gloves and gowns was not monitored.
MacIntyre, et al. 2013.[25]	19 hospitals in Beijing, China: EDs	1,669 hospital-based workers: nurses, doctors, or ward clerks	Targeted N95 use Vs Continuous N95 use vs FRMS	Rate of CRI (2 or more respiratory symptoms or one respiratory symptom and a systemic symptom) was highest in medical mask (17%) vs targeted N95 (11.8%) and lowest in the continuous N95 arm (7.2%) ($P < 0.05$).	Randomised Control Trial. 1. Asymptomatic patients were not tested. 2. Vaccination status was assessed. 3. The study was only carried out for 4 weeks, followed by one week of non-mask wearing to allow for incubation periods.

				Rates of laboratory-confirmed respiratory virus infections were low and not significant between the groups.	4. Self-reported data using pocket diary (previously validated method of reporting). 5. Only conducted for 4 weeks - limitation due to seasonality of different respiratory pathogens.
MacIntyre, et al. 2014.[26]	Healthcare workers based in hospitals in Beijing, China	1441 nurses or doctors, working full time in the emergency department or respiratory wards.	N95 vs FRSM	N95 respirators were significantly protective ($p < 0.05$) against bacterial colonization, co-colonization and viral-bacterial co-infection, compared with FRSM users and the control group. Dual respiratory virus or bacterial-viral co-infections can be reduced by the use of N95 respirators. FRSMs had no significant efficacy against any outcome compared to control.	Randomised Control Trial. 1. Participants only tested if symptomatic. 2. Participants self-reporting symptoms, hours worked, and masks worn. 3. The study was only conducted for 4 weeks. 4. No information regarding vaccination history is mentioned. 5. Information about potential infection outside of working from co-workers or family was not considered.

Ng, et al. 2020.[27]	Inpatient HCWs	41 HCWs exposed to a COVID-19 positive patient	FRSM vs N95	None of the health care workers tested positive (PCR) for COVID-19 or experienced any symptoms. 85% of the staff were exposed to AGPs whilst wearing FRSM. The other 15% wore N95. There is no evidence that N95 is superior to FRSM.	Case report. 1. All patients were swabbed on the same day, ranging from 1-5 days after last exposure to the patient. 2. Methodology is poorly reported. Retrospective study design. Small study - only 41 participants with exposure to one single COVID-19 patient. No power calculation. 3. Definition of 'exposure' was an AGP of at least 10 minutes, within 2 metres of the patient. 6. Conclusion is not based on the results- no evidence to suggest N95 superior to surgical mask does not infer that a N95 and FRSM have the same efficacy.

Loeb, et al. 2004.[28]	2 hospitals in Ontario: coronary care units and ICUs with SARS patients	43 nurses	Surgical masks vs N95	Either droplet or limited aerosol generation are the means of transmission to healthcare workers (SARS). Almost 80% reduction in risk for infection for nurses who consistently wore masks (either surgical or N95). When we compared use of N95 to use of surgical masks, the relative SARS risk associated with the N95 mask was half that for the surgical mask; however, because of the small sample size, the result was not statistically significant. Our data suggest that the N95 mask offers more protection than a surgical mask.	Retrospective cohort. 1. Use of PPE determined by reviewing documentation and retrospective interviews, may be inaccurate/recall bias. 2. No power calculation. 3. Subjective measurements of exposure. 4. No comment on blinding outcome assessors to exposure (ie did the interviewers know whether the nurse had been SARS +ve?). 5. Confounders- any other possible exposure of nurses? Bank shifts at other hospitals? Contact in the break room/canteen? 6. Precision of some results questionable- large CIs and p-values (eg in manual ventilation RR).